Hello,

My name is Josiah Smith. I am a PhD student at The University of Texas at Dallas pushing the limits of efficient radar imaging algorithms for emerging applications

Today, I am going to show you the strides we have been making to enable radar imaging for edge applications such as creating high-resolution SAR images with only your smart phone.

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While traditional SAR imaging systems, such as the airport QPS scanner, require highly controlled environments to achieve precise SAR array positioning, several emerging applications hope to perform SAR imaging in suboptimal conditions.

For example, recent progress has been made towards using smart phones to create SAR images and achieving SAR with automotive radars on self-driving cars.

However, due to the non-ideal positioning of the synthetic array elements, the imaging algorithms required for these applications deem them infeasible because of excessive computational complexity, especially on mobile platforms.

In this research, we propose a novel imaging algorithm that leverages the computational efficiency of simple SAR image reconstruction techniques with the advantages of small-platform MIMO radars with non-cooperative scanning motion, such as moving your smart phone back and forth by hand.

We will assume that the position of the antenna at each radar transmission is known. This has already been shown feasible in the literature using common depth camera and IMU sensor systems commonly employed in smart phones. We will demonstrate an efficient imaging algorithm capable of reconstructing high-resolution images in non-ideal array conditions.

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For applications such as freehand smart phone imaging and automotive SAR imaging, as the radar platform is scanned back and forth, it generally will not follow the optimal pattern of traditional SAR system, along some perfect linear or planar geometry.

Rather, it will consist of captures taken across different planes in space. We will describe this phenomenon as the multi-planar concept.

For the simple 2-D case the multi-planar concept reduces to what is shown on the left, the multi-linear case. Here, the MIMO radar captures are taken across different z-L lines in 2-D space, where the optimal array would have been a linear array.

For the 3-D case, the data are captured at different z-L planes while the target remains stationary. Hence, each round-trip distance from the transmitter to the target to the receiver will depend on the Tx/Rx pair as well as the z-L plane.

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Considering the multi-planar geometry, we propose a solution to project the MIMO data from different z-L planes to SISO data on a single Z-0 plane. We simultaneously compensate for the z-L plane mismatch and MIMO-to-SISO mismatch.

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Considering a MIMO transceiver pair at the z-L plane, we assume that the z-L plane is separated from the Z-0 plane by some distance d-L-z. Similarly, the Tx and Rx elements are separated along the x and y-directions by d-L-x and d-L-y.

Then, we apply a Taylor series expansion of the round-trip distance for small values of d-L-x, d-L-y, and d-L-z.

Using the linear and quadratic terms, the round-trip distance can be approximated as shown in bold, where R-0, the distance from the virtual SISO element to the target point. The approximation is merely a sum of 2-R-0 and some terms dependent on d-L-x, d-L-y, d-L-z, and Z-0, all known constants.

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Substituting in the approximation into the FMCW radar signal model allows us to write the equivalent SISO beat signal at the Z-0 as a product of the L-th MIMO beat signal at the z-L plane with a phase compensation factor.

By this analysis, we can project our non-cooperatively scanned data at different planes with a MIMO array to simple planar data on the Z-0 plane. Thus, we can employ efficient algorithms for SISO planar image reconstruction on the compensated data.

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To validate our approach, we will compare our algorithm to the common approaches in the literature. For non-cooperative array geometries, the back projection algorithm, or BPA, is the technique of choice in prior work and is commonly considered the gold standard. However, the computational complexity of the BPA is on the order or O of n to the sixth.

On the other hand, the naïve approach is to ignore the multi-planar geometry and use an algorithm designed for planar data, the range migration algorithm, or RMA. The RMA is much more efficient than the BPA, on the order of O of n cubed log n; however, it does not compensate for the multi-planar nature of the data.

Our approach employs the simple phase compensation discussed on the previously slides and subsequently uses the efficient RMA to create a high-resolution image.

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To verify our algorithm in simulation, we simulate a simple multi-linear array with two point-targets as shown here. The antenna elements are perturbed by Gaussian noise with a standard deviation of 2 cm.

The images on the right demonstrate the efficacy of our approach. The BPA produces a high-quality image; however, it requires 5 minutes of computation time on our machine. The RMA is unable to resolve the two points with any success.

Our algorithm, on the other hand, achieves similar image quality to the BPA with identical run-time as the RMA.

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Similarly, we simulate a rectangular cutout with a multi-planar array perturbed by Gaussian noise.

Looking at 2-D slices of the 3-D reconstructed image, we notice our image is again nearly identical to the optimal BPA image while requiring much less computation time. Our approach can reconstruct a 2-D image in 1 second while the BPA requires 3 hours. Similarly, a 3-D image can be reconstructed with our method in 14 seconds that requires 150 hours to compute using the BPA.

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To evaluate the performance of our approach on real scanning data, we emulate the non-cooperative multi-planar array scenario with our planar scanner by performing multiple scans with the target at different z-L planes.

Then, we sample the different scans to emulate the multi-planar scenario.

Again, we will compare our algorithms performance to the BPA and RMA in terms of computational complexity and image quality.

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Using real data collected by our SAR scanner, we attempt image reconstruction with the three methods discussed prior. In this case, our array is perturbed by a uniform random noise.

The results hold consistent with the simulation case. The BPA and our algorithm perform nearly identically in terms of image quality, while the RMA cannon resolve the cutout.

However, our technique matches the RMA computation time, significantly undercutting that of the BPA.

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Lastly, we sample from our multi-planar data to emulate the freehand scenario where the radar platform is assumed to move in a semi-continuous motion, rather than completely random motion.

Again, our algorithm performs as expected, requiring minimal computation power and achieving high spatial resolution.

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In conclusion, we have developed a robust algorithm for efficient image reconstruction for non-cooperative scanning geometries.

Our technique enables previously infeasible problems such as freehand smart phone imaging by offering the same computational complexity as the efficient SISO RMA with comparable image quality to the BPA.

We are in the process of pushing this work through to publication and are continuing to pursue new applications, especially in the automotive imaging arena.

Thanks for attending this presentation. I will now pass it over to Bhaskar.